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ANALYSIS OF STRESSES OF GRAPHITE /EPOXY COMPOSITE PLATE USING HYPERMESH

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ABSTRACT

In recent years, usages of composite materials have progressed in automobile, aerospace industries and it is one of the alternatives for metal materials. This trend is because of their high strength to weight ratio and also it is possible to manufacture components as per required mechanical properties. Therefore the role of stresses is very important in composites. Hence an accurate understanding of their structural behavior is required, such as stresses both normal and shear stresses. Numerical analysis has been carried out for Graphite/Epoxy Composite laminate to find the stresses of a laminated composite plate subjected to axial loads along X & Y directions of the specimen. In the numerical method, the stresses are developed for plies of orientation ($0^0/30^0/-45^0$) in the laminated composite and simulate the numerical values developed using HYPERMESH 13.0 for validation.

This work presents a stress analysis of Graphite/Epoxy laminated composite plate. In the present work, the stress behavior of laminated composite plates under Tensile loading using a four-node element with six degrees of freedom at each node and translations in the x and y directions is done. The static stress analysis includes the all types of stress behavior in diagrammatic form and results are plotted for investigation. In the present study, the modeling is done in HYPERMESH 13.0. The study investigations were carried on plates starting with three layers of the top location of 0^0 angle -ply laminated composite plates at the clamped boundary condition.

This work also contains, a number of Finite element analyses carried out for various aspect ratios and modulus ratios to study the effect of stresses of laminated composite plates subjected to tensile load. The HYPERMESH results showed, on the stresses. The effect of increasing the aspect ratio is to decrease the stresses. The composite plate has been analyzed various modulus ratios and their effects on stresses so as to find the optimized conditions.

KEYWORDS: Laminated Composite Plate, Numerical Method, Ply Orientation, Aspect Ratio, Modulus Ratio & HYPERMESH 13.0

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INTRODUCTION

The Composite material is a material composed of two or more distinct phases and having bulk properties significantly different from those of any of the constituents. The individual layers consist of high-modulus, high-strength fibers in a polymeric, metallic, or ceramic matrix material. Typical fibers used include cellulose, graphite, glass, boron, and silicon carbide, and some matrix materials are epoxies, polyamides, aluminum, titanium, and alumina. The aspect ratio of a geometric shape is the ratio of its sizes in different dimensions. For example, the

aspect ratio of a rectangle is the ratio of its longer side to its shorter side, the ratio of width to height, when the rectangle is oriented as a landscape.

LITERATURE REVIEW

Hajianmaleki [1] presented a review of the analysis of laminated composite structures used in recent decades. Jun et al. [2] Introduced a dynamic finite element method for free vibration analysis of generally laminated composite beams on the basis of first-order shear deformation theory. The influences of Poisson effect, couplings among extensional, bending and torsional deformations, shear deformation and rotary inertia are incorporated in the formulation. The dynamic stiffness matrix is formulated based on the exact solutions of the differential equations of motion governing the free vibration of the generally laminated composite beam. Rarani et al. [3] used analytical and finite element methods for prediction of buckling behavior, including critical buckling load and modes of failure of thin laminated composites with different stacking sequences. A semi-analytical Rayleigh–Ritz approach is first developed to calculate the critical buckling loads of square composite laminates with SFSF boundary conditions. Then, these laminates are simulated under axial compression loading using the commercial finite element software, ABAQUS. Critical buckling loads and failure modes are predicted by both eigenvalue, linear and nonlinear analysis. Alnefaie [4] developed a 3D-FE model of delaminated fiber reinforced composite plates to analyze their dynamics. Natural frequencies and modal displacements are calculated for various case studies for different dimensions and delamination characteristics. Numerical results showed a good agreement with available experimental data. A new proposed model shows enhancement of the accuracy of the results in different aspect ratios. Roos and Bakis [5] analyzed the flexible matrix composites which consist of low modulus elastomers such as polyurethanes which are reinforced with high-stiffness continuous fibers such as carbon. Sadr and Bargh [6] studied the fundamental frequency optimization of symmetrically laminated composite plates using the combination of Elitist- Genetic algorithm (E-GA) and finite strip method (FSM). Kayikci and Sonmez [7] studied and optimized the natural frequency response of symmetrically laminated composite plates. Khandanet al. [8] Researched and added an extra term to the optimization penalty function in order to consider the transverse shear effect. Montagnier and Hochard [9] studied the optimization of hybrid composite drive shafts operating at subcritical or supercritical speeds, using a genetic algorithm. Rocha *et al*. [10] presented a genetic algorithm combining two types of computational parallelization methods, resulting in a hybrid shared/distributed memory algorithm based on the island model using both Open MP and MPI libraries

METHODOLOGY

Problem Solving Procedure for Analytical Method

There are many element types available to model layered composite materials. In our FE analysis, the linear layered structural shell element is used. An accurate representation of irregular domains (i.e. Domains with curved boundaries) can be accomplished by the use of refined meshes and/or irregularly shaped elements. The linear layered 8-node structural shell element with six degrees of freedom is shown in Figure 1. Nodes are represented by I, J, K, L, M, N, O, and P.

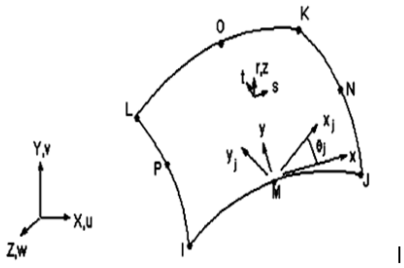


Figure 1: Geometry of 8-Node Element with Six Degrees of Freedom

The engineering elastic constants of the unidirectional graphite/epoxy lamina are

E_1 = 181 GPa, E_2 = 10.3 GPa, ν_{12} = 0.28, G_{12} = 7.17 GPa.

Compliance matrix elements are,

$S_{11} = \frac{1}{E1} Pa^{-1}$

$S_{12} = \frac{-\vartheta 12}{E1} Pa^{-1}$

$S_{22} = \frac{1}{E2} Pa^{-1}$

$S_{66} = \frac{1}{G12} Pa^{-1}$

And the ϑ_{21}term is called the minor poission's ratio. We have the reciprocal relationship

$$\frac{\vartheta_{12}}{E_1} = \frac{\vartheta_{21}}{E_2}$$

$$\vartheta_{21} = \frac{\vartheta_{12}}{E_1} \times E_2$$

The reduced stiffness matrix $[Q]$ elements are

$Q_{11} = \frac{E_1}{1-\vartheta 21\vartheta 12} Pa$

$Q_{12} = \frac{\vartheta 12E2}{1-\vartheta 21\vartheta 12} Pa$

$Q_{22} = \frac{E2}{1-\vartheta 21\vartheta 12} Pa$

$Q_{66} = G_{12} Pa$

The compliance matrix for an orthotropic plane stress problem can be written as,

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix}$$

Reduced stiffness matrix for 0° graphite/epoxy ply is

$$[Q] = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix}$$

The transformed, reduced stiffness matrix $[\bar{Q}]$ for each of the three plies is

$$[\bar{Q}] = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}$$

The total thickness of the laminate is h= 0.005×3 = 0.015 m

The midplane is 0.0075 m from the top and the bottom of the laminate.

The locations of ply surfaces are

h_0: -0.0075 m

h_1: -0.0025 m

h_2: +0.0025 m

h_3: +0.0075 m

The arrangement is shown in figure 2

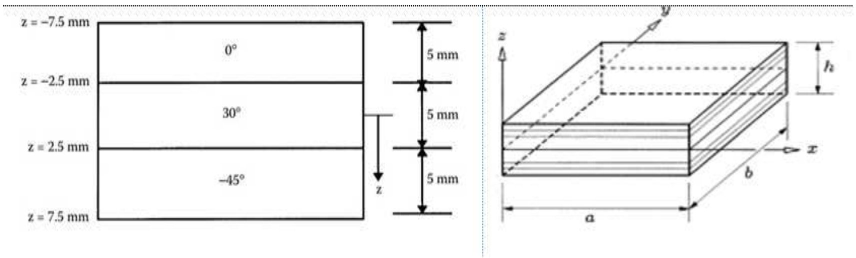


Figure 2: Schematic Diagrams of Plies

Now find $[A]$ → extensional stiffness matrix

$[B]$ → coupling stiffness matrix

$[D]$ → bending stiffness matrix

Where, Extensional stiffness matrix$[A]$is

$$A_{ij} = \sum_{k=1}^{n} \left[\left(\bar{Q}_{ij}\right)\right]_k (h_k - h_{k-1}) \;\; i = 1,2,6;\; j = 1,2,6;$$

Coupling stiffness matrix $[B]$ is

$$B_{ij} = \frac{1}{2}\sum_{k=1}^{3} \left[\bar{Q}_{ij}\right]_k \left({h_k}^2 - {h_{k-1}}^2\right) \;\; i = 1,2,6;\; j = 1,2,6;$$

The bending stiffness matrix $[D]$ is

$$D_{ij} = \frac{1}{3}\sum_{k=1}^{3} \left[\bar{Q}_{ij}\right]_k \left({h_k}^3 - {h_{k-1}}^3\right) i = 1,2,6;\; j = 1,2,6;$$

Because the applied load is N_x=N_y=1000 N/m

The midplane and strains and curvatures are found by solving the following set of six simultaneous linear equations

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix}_{6\times6} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \\ k_x \\ k_y \\ k_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} \varepsilon^0 \\ M \end{Bmatrix} = \begin{bmatrix} A^* & B^* \\ C^* & D^* \end{bmatrix} \begin{Bmatrix} N \\ k \end{Bmatrix}$$

Where $[A^*] = [A]^{-1}$

$$[B^*] = -[A]^{-1}[B]$$

$[C^*] = [B][A]^{-1}$

$[D^*] = [D] - \{[B][A]^{-1}\}[B]$

The fully inverted form is given by

$$\begin{Bmatrix} \varepsilon^0 \\ k \end{Bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{Bmatrix} N \\ M \end{Bmatrix}$$

Where $[A'] = [A^*] - [B^*][D^*]^{-1}[C^*]$

$[B'] = [B^*][D^*]^{-1}$

$[C'] = -[D^*]^{-1}[C^*]$

$[D'] = [D^*]^{-1}$

Now solving equations to obtain strain values

$N_x=N_y=1000$ N/m

$$\begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} = [A'] \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix}$$

And calculating curvatures $\begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} = [C'] \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix}$

By using the following relations to find strains and curvatures of each ply with different orientations,

The laminate strains can be written as $\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + Z \begin{Bmatrix} K_X \\ K_Y \\ K_{XY} \end{Bmatrix}$

The plate curvature $\mathrm{K_x or K_y}$ is the rate of change of slope of the bending plate in either the x or y - direction.

$\mathrm{K_{xy}}$ Curvature term is bending in the x-axis along y -axis (twisting)

Find the strains where Z= -0.0025mm for 30^0 angle ply

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} {\varepsilon^0}_x \\ {\varepsilon^0}_y \\ {\gamma^0}_{xy} \end{Bmatrix} + Z \begin{Bmatrix} K_X \\ K_Y \\ K_{XY} \end{Bmatrix}$$

Similarly, Using the stress-strain relation for Top location of 30^0 ply

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

Procedure for Simulation Process Using HYPERMESH

Step 1: Open HYPERMESH

Step 2: Create a material

Step 3: Create a property.

Step 4: Create a component to hold the model's geometry.

Step 5: Create nodes

Step 6: Display the node numbers.

Step 7: Create straight line

Step 8: Meshing

Step 09: Create a Ply Laminate

Step 10: Create a Load Collector

Step 11: Apply Constraints

Step 14: Load Steps

Step 15: Optistruct

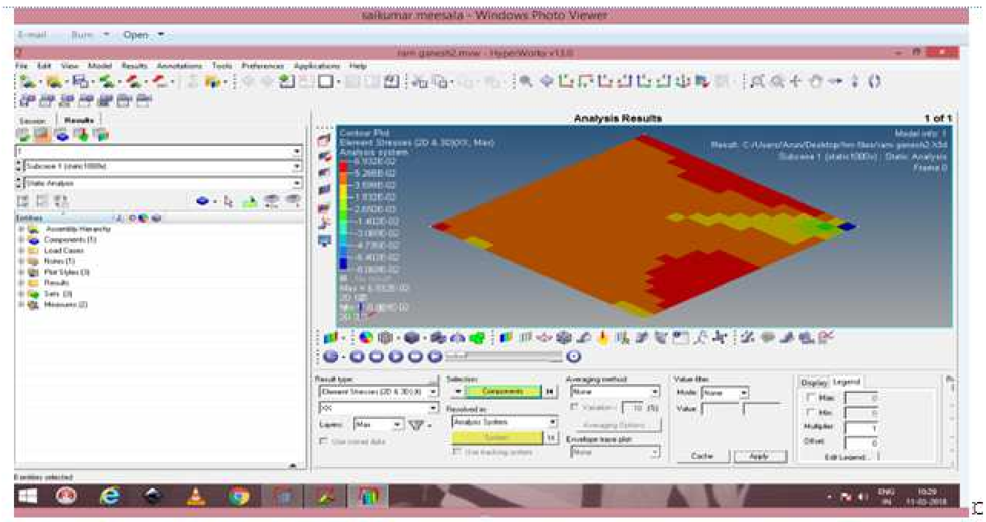


Figure 3

RESULTS & DISCUSSIONS

Using HYPERMESH software the layered composite is analyzed using different aspect ratios of 2, 3 4 and 5 . This is considered with the modular ratio (E1/E2) of 1,2,3,4 and 5. The stresses in X and Y direction are considered as results for normal stress and also for shear stress and are tabulated in table 1,2,3, and 4.

Table 1: Tabulation of Results, when the Aspect Ratio is 2

Design Parameter	When E1/E2 Ratio =1	When E1/E2 Ratio =2	When E1/E2 Ratio =3	When E1/E2 Ratio =4	When E1/E2 Ratio =5
Stress in X Direction(MPa)	4.389e^{-2}	4.412e^{-2}	4.407e^{-2}	4.395e^{-2}	4.381e^{-2}
Stress in Y Direction(MPa)	2.343e^{-2}	2.310e^{-2}	2.281e^{-2}	2.257e^{-2}	2.236e^{-2}
Shear Stress(MPa)	7.580e^{-3}	7.964e^{-3}	1.035e^{-2}	1.252e^{-2}	1.451e^{-2}

Table 2: Tabulation of Results when the Aspect Ratio is 3

Design Parameter	When E1/E2 Ratio =1	When E1/E2 Ratio =2	When E1/E2 Ratio =3	When E1/E2 Ratio =4	When E1/E2 Ratio =5
Stress in X Direction(MPa)	5.035e^{-2}	7.171e^{-2}	8.460e^{-2}	9.358e^{-2}	1.003e^{-1}
Stress in Y Direction(MPa)	2.161e^{-2}	2.128e^{-2}	2.099e^{-2}	2.075e^{-2}	2.055e^{-2}
Shear Stress(MPa)	2.842e^{-2}	3.021e^{-2}	3.222e^{-2}	3.308e^{-2}	3.351e^{-2}

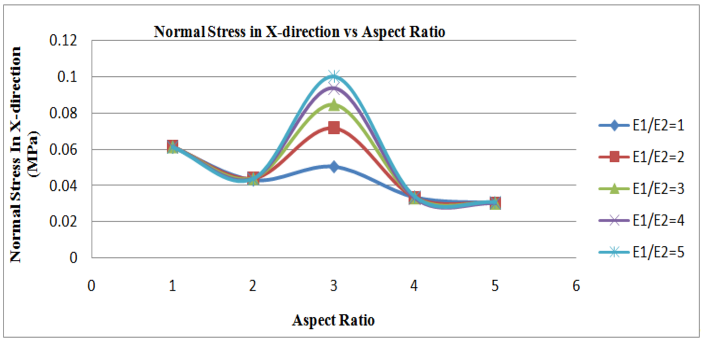
Table 3: Tabulation of Results when the Aspect Ratio is 4

Design Parameter	When E1/E2 Ratio =1	When E1/E2 Ratio =2	When E1/E2 Ratio =3	When E1/E2 Ratio =4	When E1/E2 Ratio =5
Stress in X Direction(MPa)	3.336e^{-2}	3.348e^{-2}	3.341e^{-2}	3.331e^{-2}	3.403e^{-2}
Stress in Y Direction(MPa)	1.833e^{-2}	1.80e^{-2}	1.77e^{-2}	1.756e^{-2}	1.833e^{-2}
Shear Stress(MPa)	6.101e^{-3}	5.813e^{-3}	7.560e^{-3}	9.11e^{-3}	1.051e^{-2}

Table 4: Tabulation of Results when the Aspect Ratio is 5

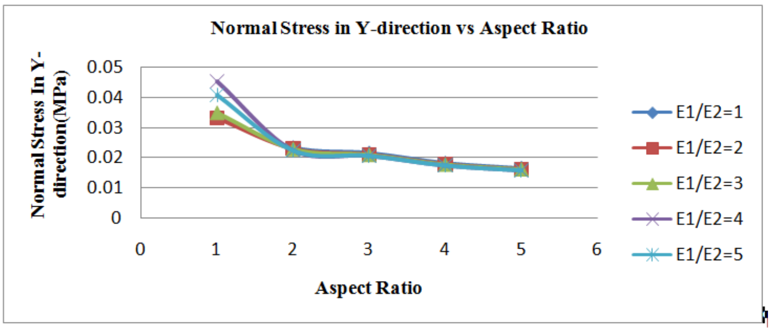
Design Parameter	When E1/E2 Ratio =1	When E1/E2 Ratio =2	When E1/E2 Ratio =3	When E1/E2 Ratio =4	When E1/E2 Ratio =5
Stress in X Direction(MPa)	3.034e^{-2}	3.043e^{-2}	3.037e^{-2}	3.027e^{-2}	3.092e^{-2}
Stress in Y Direction(MPa)	1.666e^{-2}	1.638e^{-2}	1.614e^{-2}	1.594e^{-2}	1.578e^{-2}
Shear Stress(MPa)	5.388e^{-3}	4.987e^{-3}	6.503e^{-3}	7.852e^{-3}	9.074e^{-3}

With the tabulated values, different graphs are generated as shown in Graph1, 2 and 3



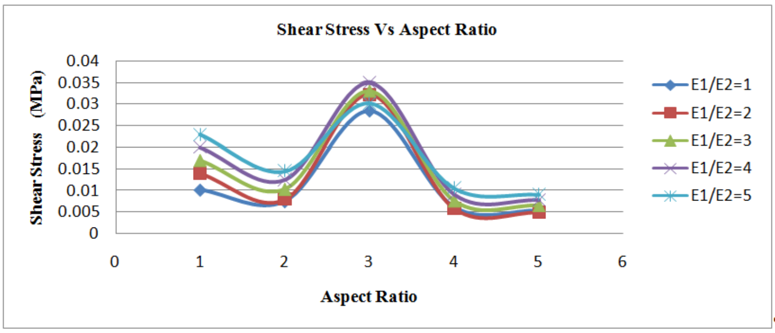
Graph 1: Normal Stress in X-Direction Vs Aspect Ratio

From the graph, the lesser values of normal stresses in X-direction are observed when the aspect ratio is 5 for various modulus ratios (i.e, when E1/E2=1, 2, 3, 4, 5)



Graph 2: Normal Stress in Y-Direction Vs Aspect Ratio

From the graph, the lesser values of normal stresses in Y-direction are observed when the aspect ratio is 5 for various modulus ratios (i.e, when E1/E2=1, 2, 3, 4, 5)



Graph 3: Shear Stress Vs Aspect Ratio

From the graph, the shear stress behavior is entirely different within stress in X and y direction of the layered composite plate. The lesser values shear stresses are observed when the aspect ratio is 5 for various modulus ratios (i.e, when E1/E2=1, 2, 3, 4, 5)

CONCLUSIONS AND FUTURE SCOPE OF WORK

The composite plies are analyzed for optimum conditions for different aspect ratios and modulus ratios using HYPERMESH. The results are successfully developed and the following Conclusions are drawn from the present work is as follows: 1. The lesser values of normal stresses in X-direction and Y-Dirction are observed when the aspect ratio is 5 for various modulus ratios (i.e, when E1/E2=1,2,3,4,5). The behavior of shear stress is concerned, lesser values shear stresses are observed when the aspect ratio is 5 for various modulus ratios (i.e, when E1/E2=1,2,3,4,5)

Future Scope of Work

The work may further extend to other PMC composites.

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